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Distributed Modular Input/Output System with Wireless Backplane Extender

Cross-Reference to Related Application

This application claims priority from and benefit of the filing date of U.S. provisional application Ser. No. 60/520,849 filed November 17, 2003, and the 60/520,849 provisional application is hereby expressly incorporated by reference into this application.

Background

Industrial automation control systems comprise an industrial controller, which is a special purpose computer used for controlling industrial processes and manufacturing equipment on a real-time basis. Under the direction of a stored program, the industrial controller examines a set of inputs reflecting the status of the controlled process and changes a set of outputs controlling the industrial process. The inputs and outputs may be binary or analog. Typically, analog signals are converted to binary data for processing.

Industrial controllers differ from conventional computers in that their hardware configurations vary significantly from application to application reflecting their wide range of uses. This variability is accommodated by constructing the industrial controller on a modular basis having removable input and output (I/O) modules that may accommodate different numbers of input and output points depending on the process being controlled. The need to connect the I/O modules directly to or adjacent different pieces of machinery that may be spatially separated has led to the development of distributed I/O systems that take a variety of forms. In one example, a single discrete or "block" I/O module is located where desired. The block I/O module typically contains digital or analog I/O circuits or a combination of both, a built-in power supply, and a built-in network adapter for communicating with the industrial controller. In another example, the distributed I/O installation is modular in the sense that a single network adapter module is

connected to the data network at a point remote from the industrial controller, and one or more I/O modules, as needed, are connected to the network adapter module for communication with the industrial controller through the single network adapter module.

In these modular distributed I/O products, the individual I/O modules communicate with the network adapter module by means of a backplane. In some cases, the backplane is constructed in advance to have a finite number of slots each adapted to receive an I/O module, and the I/O modules (or a non-functional filler module) are plugged into the slots of the backplane. In others, the backplane has no predetermined structure and is built by interconnecting I/O modules to each other, either directly or using cables.

In either case, known modular products for distributed I/O applications are sometimes found to be sub-optimal for particular installations. When the distributed I/O system has a finite number of slots available to receive an I/O module, the number of slots can sometimes by insufficient. In the case where the backplane is constructed as and when the I/O modules are interconnected, the physical size of the I/O system can become undesirably large and can exceed the available mounting space on the machine being controlled and/or in an enclosure.

In some cases, cables have been used to extend a backplane from a first mounting location to a second mounting location, e.g., from a first fixed-length backplane to a second, or from a first enclosure to a second, to allow the various I/O modules to communicate with the industrial controller through a single network adapter. While this backplane extension technique is often effective, it does have numerous drawbacks including the relatively high cost of cables and the cable-to-backplane interface, the limited distance (about 1 meter), degradation of the electrical signals, wire congestion, possibilities for environmental contaminations at the cable-to-backplane connection. Also, in some cases, cables cannot be used due to moving machine parts or other undesirable environmental conditions.

In light of the foregoing issues and others, a need has been found for a wireless backplane extender for a distributed modular input/output system in an industrial automation control system.

Summary

In accordance with the present development, a distributed modular input/output system includes a primary wireless device adapted to be operatively connected to an associated industrial controller. A secondary wireless device is physically disconnected from the primary wireless device. The secondary wireless device is operatively connected to the primary wireless device by a primary wireless backplane link. At least one input/output module is operatively connected the secondary wireless device. An associated field device can be connected to the at least one input/output module for communication with the associated industrial controller via the secondary wireless device, the primary wireless backplane link, and the primary wireless device.

Brief Description of the Drawings

The development comprises components and arrangements of components, and/or various steps and arrangements of steps, preferred embodiments of which are disclosed herein and shown in the drawings that form a part hereof, wherein:

FIG. 1 (prior art) is a simplified perspective view, partially in phantom, of a distributed modular I/O system having an network adapter (adapter) communicating on a backplane to one or more detachable I/O modules;

FIG. 2 (prior art) is a block diagram of the distributed I/O system of FIG. 1 showing the interconnection of the adapter to the I/O modules via backplane data conductors and slot address signals;

FIG. 3 (prior art) is simplified diagrammatic illustration showing the distributed modular I/O system of FIG. 1 as part of an overall industrial automation control system that receives input from and sends output to an industrial process;

FIG. 4 (prior art) is a schematic illustration of an industrial automation control system including a distributed modular input/output system with a conventional backplane extender formed in accordance with the present development;

FIG. 5 is a schematic illustration of an industrial automation control system including a distributed modular input/output system with a wireless backplane extender formed in accordance with the present development;

FIG. 5A diagrammatically illustrates the master (primary) and servant (secondary) wireless modules of the distributed modular input/output system of FIG. 5;

FIG. 6 schematically illustrates an industrial automation control system including a second embodiment of a distributed modular input/output system with a wireless backplane extender formed in accordance with the present development;

FIG. 6A illustrates another embodiment of a distributed modular input/output system with a wireless backplane extender formed in accordance with the present development;

FIG. 7 illustrates an example mixed-environment application for the distributed modular input/output system with a wireless backplane extender formed in accordance with the present development;

FIG. 8 graphically illustrates an example method by which the primary (master) wireless device communicates with the various secondary (servant) wireless devices;

FIGS. 9A and 9B illustrates examples for the primary wireless and secondary wireless devices M and S1-S6, respectively.

Detailed Description

Referring now to FIG. 1, an example I/O system **10** for use with an industrial controller includes a network adapter module **12** providing a connection **14** to an industrial network **16.** The data network **16** may be any one of a number of industrial control or I/O networks including but not limited to ControlNet, DeviceNet, EtherNet/IP, RIO, ASi, PROFIBUS, PROFInet, Foundation Fieldbus or the like as are well known in the art of industrial automation networks. The adapter module **12** communicates over the network **16** with an industrial controller to receive output data from the industrial controller or to provide input data to the industrial controller

to be processed according to a control program. The network **16** can be hard-wired or wireless.

The adapter module **12** communicates with a backplane circuit **18** (often referred to simply as the "backplane") to connect it to one or more I/O modules **20.** The I/O modules **20** connect via I/O lines (e.g., electrical cables, fiber optic cables, etc.) **24** with a controlled process **26** which can be a machine or other device or process, or several or portions of same. As is understood in the art, the I/O modules **20** convert digital data received over the backplane **18** from the adapter module **12** into output signals (either digital or analog) in a form suitable for input to the industrial process **26**. The I/O modules **20** typically also receive digital or analog signals from the industrial process **26** and convert same to digital data suitable for transmission on the backplane **18** to the adapter module **12** and, thereafter, to the industrial controller.

Modularity of the I/O system **10** is provided through a connector **28** on each I/O module **20** which may be mated with any one of a number of connectors **30** extending from the backplane **18**. The connectors **30** are each associated with "slots" providing mechanical features (not shown) for otherwise securing the I/O module **20**. As noted, in other, more modular arrangements, the I/O modules **20** are interconnected with each other to define the backplane **18** in a "build-as-you-go" fashion where the backplane **18** passes through the modules **20,** themselves.

In the shown parallel bus embodiment, connectors **30** receive parallel data bus conductors **32**, over which data may be read and written, and slot address signals **34** which are enabled one at a time to indicate the slot and hence the particular I/O module **20** for which the data of data bus conductors **32** is intended or from which data is being solicited. The data bus conductors **32** also include control lines including a clock and read/write line indicating timing for a data transfer according to techniques well known in the art. In an alternative serial bus embodiment, not shown, slot address signals are attached to the data blocks sent over a serial data bus connector or are implicit in the ordering or timing of the data blocks being sent.

Referring now to FIG. 2, the adapter module **12** includes a network interface **35** communicating with the connector **14** to decode and encode data exchanged with the network **16**. The network interface **35** in turn communicates with an internal bus **36** which connects the network interface **35** to a processor **38** and a memory **40**. The memory **40** includes a buffer **42** (divided into input and output sections) and an operating program **44** allowing the processor **38** to operate on the data passing on the internal bus **36** according to the methods of the present invention as will be described. The adapter module **12** also may include a power supply **PS** or an external power supply can feed the module.

The internal bus **36** also connects to backplane data interface **46** and backplane address decoder **48**. I/O modules **20a-20c** (indicated generally at **20** in FIG. 1), when connected to the backplane **18**, communicate with the data bus conductors **32** and slot address signals **34** via a backplane interface **50a-50c**, respectively. In the most general terms, each I/O module **20a-20c** comprises I/O circuitry **C** that: (i) connects via I/O lines **24** with a controlled process **26**; (ii) converts digital data received over the backplane **18** from the adapter module **12** into output signals (either digital or analog) in a form suitable for connection to the industrial process **26**; and/or, (iii) receives digital or analog signals from the industrial process **26** and converts it to digital data suitable for transmission on the backplane **18** to the adapter module **12**.

More particularly, in each I/O module **20a-20c**, backplane interface **50a-50c** (each component denoted a-c to reflect the particular I/O module) in turn communicates with an internal bus **52a-52c**, which communicates with an internal processor **54a-54c** and memory **56a-56c**, the latter which includes a buffer portion **58a-58c** and an operating program **60a-60c**. The internal bus **52a-52c** also communicates with I/O circuitry **62a-62c** that provides level shifting, conversion and filtering necessary for the interface to the controlled process. The processor **54a-54c** and memory **56a-56c** of a respective I/O module **20a** can be replaced with a state machine.

FIG. 3 illustrates the conventional modular I/O system **10** of FIGS. 1 and 2 (including an adapter module **12** and five I/O modules **20**, i.e., **20a-20e**) as part of an industrial automation control system for controlling the industrial process **26**. More particularly, an industrial controller **IC** comprising a scanner **S** connected to the data network **16**. As is generally known in the art, the scanner **S** provides an interface between the devices connected to network **16** and a PLC of the industrial controller **IC**. The modular I/O system **10** is connected to the network **16** via network adapter **12** and is located remotely from the controller **IC** (as shown the modular I/O system **10** is located on/adjacent the process **26**, e.g., mounted directly to the machine being controlled). As noted above, the modular I/O system **10** comprises multiple I/O modules **20a-20e** that communicate with the adapter **12** by way of a backplane **18**. The I/O circuits **C** (FIG. 2) of the modules **20a-20e** connect via I/O lines **24** such as cables with input or output field devices of the controlled process **26**, respectively. The I/O circuits **C** convert digital data received from controller **IC** via network adapter **12** into output signals (either digital or analog) for input to the industrial processes **26** via lines **24** and the field devices (e.g., valves, motors, actuators, visual displays, audio devices, etc.) connected thereto. Likewise, the I/O circuits **C** receive digital or analog signals from the industrial processes **26** via lines **24** and the field devices (e.g., sensors, switches, detectors, timers, etc.) and convert same to digital data suitable for input to controller IC via network adapter **12**.

As described briefly above, in some cases, cables have been used to extend the backplane **18** from a first mounting location to a second mounting location to allow the various I/O modules **20** to communicate with the same network adapter **12**. FIG. 4 illustrates such an arrangement wherein the conventional modular I/O system **10** has been divided into a first portion **10A** mounted to a first part **26A** of the machine **26** (or, alternatively in a first enclosure or other location) and a second portion **10B** mounted to a second part **26B** of the machine **26** (or, alternatively in a second enclosure or other location). The first portion **10A** of the system comprises the adapter module **12** and the I/O modules **20a,20b** that communicate with the

adapter module **12** via first backplane section **18A**. The second portion **10B** of the system comprises the I/O modules **20c,20d,20e** that are connected to and/or cooperate to define a second backplane section **18B**. A cable **18E** extends between the I/O modules **20b,20c** and electrically interconnects the backplane sections **18A,18B** for data transfer therebetween. As noted above, however, backplane extension cables such as the cable **18E** have several undesirable attributes such as, e.g., relatively high cost, limited distance (about 1 meter), degradation of the electrical signals, wire congestion, possibilities for environmental contaminations at the cable-to-backplane connection points and interference with moving machine parts or other environmental factors.

FIG. 5 shows a distributed modular input/output system with wireless backplane extender **100** formed in accordance with the present development. Except as otherwise shown and/or described, the modular input/output system **100** is identical to the system **10** described above and, as such, like components are identified with reference numbers that are **100** greater than those used in FIGS. 1-4. The modular input/output system forms part of an industrial automation control network for controlling the industrial process **26** having first and second portions **26A,26B** (processes **26A,26B** need not be related). More particularly, the industrial automation control network comprises an industrial controller **IC** comprising a scanner **S** connected to the data network **16**. The modular I/O system **100** is connected to and communicates with the data network **16** via network adapter **112** and is located remotely from the controller **IC**. The modular I/O system **100** comprises multiple I/O modules **120a-120e** that communicate with the industrial controller **IC** via network adapter **112**. The I/O circuitry of each module **120a-120e** connects via I/O lines **24** such as cables with input or output devices of the controlled process **26** and: (i) convert digital data received from controller **IC** via network adapter **112** into output signals (either digital or analog) for input to the industrial processes **26** via lines **24**; and, (ii) receive digital or analog signals from the industrial processes **26** via lines **24** and convert same to digital data suitable for input to controller **IC** via network adapter **112**.

With continuing reference to FIG. 5, the modular I/O system **100** comprises a first portion **100A** mounted to a first part **26A** of the machine **26** and a second portion **100B** mounted to a second part **26B** of the machine **26**. The first portion **100A** of the modular I/O system **100** comprises the adapter module **112** and the I/O modules **120a,120b** that communicate with the adapter module **112** via first (master) backplane section **118A** that is predefined or defined by the modules **112,120a,120b**. The second portion **100B** of the modular I/O system **100** comprises the I/O modules **120c,120d,120e** that are connected to and/or cooperate to define a second (servant) backplane section **118B**. The modular I/O system **100** further comprises a wireless backplane extender **170** defined by a wireless master device **170m** (also referred to as a primary wireless device **170m**) and a wireless servant device **170s** (also referred to as a secondary wireless device **170s**). The wireless master device **170m** forms a part of the first portion **100A** of the modular I/O system **100** and is operatively connected to or partially defines the first backplane section **118A** for data and power communication therewith. The wireless servant device **170s** forms a part of the second portion **100B** of the modular I/O system **100** and is operatively connected to or partially defines the second backplane section **118B** for data and power connection therewith. The first portion **100A** of the system **100** receives electrical power by connecting the adapter module **112** (as shown) and/or one or more of the I/O modules **120a,120b** and/or the wireless master device **170m** to a source of electrical power $\mathbf{P_m}$. The second portion **100B** of the system **100** receives electrical power by connecting the wireless servant device **170s** (as shown) and/or one or more of the I/O modules **120c,120d,120e** to a source of electrical power $\mathbf{P_s}$. It should be recognized that the wireless master device **170m** can form a part of the scanner **S** in order to eliminate the network adapter **112** and network connections **16,14** shown in Fig. 5 between the scanner **S** and the network adapter **112**. In one such example, the industrial control network can be an industrial control platform (ICP) such as the Allen-Bradley ControlLogix platform and the wireless master device **170m** is connected directly to the ControlLogix backplane.

The wireless master device **170m** and the wireless servant device **170s** are adapted to establish therebetween a wireless backplane link **118W** that forms a data communication path for seamless bi-directional transfer of data between the first and second backplane sections **118A,118B**. In the preferred embodiment, the wireless backplane link **118W** comprises a radio frequency (RF) connection between the wireless master and servant devices **170m,170s** and, as such, these devices are shown as comprising respective antennae **172m,172s** that transmit and receive the RF signal.

The wireless backplane link **118W** can be established according to any suitable RF signal protocol, but is preferably implemented according to an IEEE 802.11 based protocol, e.g., 802.11b or another, such as, e.g., Bluetooth, ultra-wideband (UWB), frequency hopping spread spectrum (FHSS), direct sequence spread spectrum (DSSS), orthogonal frequency division multiplex (OFDM). It is not intended that the development be limited to a particular wireless protocol and others can be used without departing from the overall scope and intent of the invention. It is also not intended that the wireless backplane link **118W** be limited to RF signals; other suitable means, e.g., infrared and other light wavelengths, ultrasonic links, and others can be utilized without departing from the overall scope and intent of the invention. Furthermore, the master-servant relationship between the wireless devices **170m,170s** can be altered to be a peer-to-peer relationship without departing from the invention. In such case, either wireless device **170m,170s** can initiate communication on the wireless backplane link **118W** with each other, and the terms "master" and "servant" as used herein are not intended to limit the development to a master-servant arrangement (sometimes also referred to as a "master-slave" relationship) where only the master device **170m** can initiate communication on the wireless backplane link **118W**.

Regardless of the protocol by which the wireless backplane link **118W** is implemented for wireless (tether-free) communication of backplane data between the master and servant devices **170m,170s**, the data transfer protocol implemented on the wired backplane sections **118A,118B** is also implemented on

the wireless backplane link **118W** via encapsulation so that the wireless link is completely transparent. As shown in FIG. 5A, the hard-wired backplane sections **118A,118B** are used to transfer data to and from according to any suitable known protocol such as, e.g., DeviceNet, ControlNet, POINTBus, etc. The wireless master device **170m** and the wireless servant device **170s** comprise respective encapsulation/decapsulation modules **174m,174s** that encapsulate data received from and decapsulate data to be transmitted to the hard-wired backplane sections **118A,118W**. In this manner, the wireless backplane link **118W** behaves identically to a backplane extender cable such as that shown at **118E** in FIG. 4.

In an industrial automation environment, such as the network shown in FIG. 5, it is critical that the wireless backplane link **118W** be established and maintained at the optimum signal strength. To that end, the wireless master device **170m** and each wireless servant device **170s** comprise respective wireless signal link quality indicators **176m,176s** (FIG. 5A) that provide visible indicia of the quality of the RF or other wireless signal by which the wireless backplane link **118W** is established. In the illustrated embodiment, the indicators **176m,176s** each comprise a plurality of LED's or other indicator lights **178** that allow an observer to determine in the RF signal being received by the master or servant wireless device **170m,170s** is of sufficient strength to send and receive the backplane data on the wireless backplane link **118W** for operative interconnection of all I/O modules **120a-120e** to the adapter module **112** and, hence, the industrial controller **IC**.

FIG. 5 illustrates only one embodiment of a distributed modular I/O system **100** formed according to the present development. In more general terms, a distributed modular input/output system with a wireless backplane extender formed in accordance with the present development comprises at least a network adapter module **112** adapted for operative connection to the industrial controller **IC** via wired/wireless connections **14,16**, a wireless master device **170m** electrically connected to the network adapter module **112** (alone or together with one or more I/O modules **120a-120e**) via master backplane section **118A**, one or more wireless servant devices **170s** operatively connected to the wireless master device **170m** by

a wireless backplane link **118W**, and at least one I/O module **120a-120e** electrically or otherwise operatively connected to each servant wireless module **170s** by a servant backplane section **118B**. It can thus be seen that a main advantage of the system **100** is that the backplane **18** of a conventional modular distributed input/output system **10** can be interrupted and replaced with a wireless link **118W** at any desired point between the network adapter **12** and the terminal I/O module such as the module **20e** in FIG. 3.

FIG. 6 illustrates an example of such an alternative arrangement for a distributed modular input/output system with a wireless backplane extender formed in accordance with the present development for input of data to and output of data from industrial machine(s)/process(es) **26A,26B,26C** (which can be the same or different machine/process and are referred to generally as industrial process **26**) as part of an industrial automation network comprising an industrial controller **IC** and scanner **S** connected to a data network **16**. The modular I/O system **100** comprises a network adapter **112** operatively connected to the industrial controller **IC** and scanner **S** by wired and/or wireless network connections **14,16** (the network adapter is shown as being located remotely from the controller **IC** but could be located adjacent the controller **IC**, integrated with the controller **IC** and/or connected directly to the controller **IC**). The modular I/O system **100** further comprises multiple I/O modules **120a-120f** that communicate with the industrial controller **IC** via network adapter **112**. The I/O circuitry of each I/O module **120a-120f** connects via I/O lines **24A,24B,24C** such as cables with input or output devices of the controlled process **26** and: (i) convert digital data received from controller **IC** via network adapter **112** into output signals (either digital or analog) for input to the industrial processes **26** via lines **24**; and, (ii) receive digital or analog signals from the industrial processes **26** via lines **24** and convert same to digital data suitable for input to controller **IC** via network adapter **112**.

With continuing reference to FIG. 6, the modular I/O system **100** comprises a master portion **100M**, and multiple servant portions **100A,100B,100C** mounted to/adjacent the processes **26A,26B,26C**, respectively. In the illustrated

embodiment, the master portion **100M** comprises only the adapter module **112** and the wireless master device **170m** operatively connected to the adapter module **112** for data and/or power transfer via master backplane **118M**. Alternatively, the master portion **100M** can also include one or more I/O modules **120a-120f** that would typically be located physically between the network adapter module **112** and the master wireless module **170m**. The master portion **100M** is also connected to electrical power $\mathbf{P_m}$.

Servant portion **100A** of the system **100** comprises **I/O** modules **120a,120b,120c** and a wireless servant device **170s1** all operatively interconnected for data and/or power transfer by servant backplane **118A**. The I/O modules **120a,120b,120c** provide input data to and/or receive output data from the process **26A** via I/O lines **24A**. Servant portion **100A** is connected to electrical power **Pa**.

Servant portion **100B** of the system **100** comprises a single I/O module **120d** and a wireless servant device **170s2** operatively interconnected with each other for data and/or power transfer by servant backplane **118B**. The I/O module **120d** provides input data to and/or receives output data from the process **26B** via I/O line **24B**. Servant portion **100B** is connected to electrical power **Pb**.

Servant portion **100C** of the system **100** comprises I/O modules **120e,120f** and a wireless servant device **170s3** all operatively interconnected for data and/or power transfer by servant backplane **118C**. The I/O modules **120e,120f** provide input data to and/or receive output data from the process **26C** via I/O lines **24C**. Servant portion **100C** is connected to electrical power **Pc**.

The modular I/O system **100** further comprises a wireless backplane extender **170** defined by the wireless master device **170m** (also referred to as a primary wireless device **170m**) and all of the wireless servant devices **170s1,170s2,170s3** (also referred to as secondary wireless devices **170s1,170s2,170s3**). The wireless master device **170m** and the wireless servant devices **170s1,170s2,170s3** are adapted to establish therebetween respective wireless backplane links **118W1,118W2,118W3** that define tether-free data communication paths for

seamless bi-directional transfer of backplane data between the master backplane section **118M** and each of the servant backplane sections **118A,118B,118C**. Here, again, as described above, the wireless backplane links **118W1,118W2,118W3** preferably comprises a radio frequency (RF) connections between the wireless master device **170m** and the wireless servant devices **170s1,170s2,170s3** using antennae **172m,172s1,172s2,172s3** that transmit and receive the RF signal. The wireless backplane links **118W1,118W2,118W3** can be established according to any suitable RF signal protocol, but is preferably implemented according to an IEEE 802.11 based protocol, e.g., 802.11b, or another such as, e.g., Bluetooth, ultra-wideband (UWB), frequency hopping spread spectrum (FHSS), direct sequence spread spectrum (DSSS), orthogonal frequency division multiplex (OFDM). It is not intended that the development be limited to a particular wireless protocol and others can be used without departing from the overall scope and intent of the invention. In general, in the case of an RF signal, the wireless backplane links **118W1,118W2,118W3** are established by a plurality of communication channels derived from or defined by known methods and systems for sharing a segment of an RF spectrum including but not limited to, e.g., frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), spatial division multiple access (SDMA), and spread spectrum techniques including frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS), as well as hybrids of same. It is not intended that the wireless backplane links **118W1,118W2,118W3** be limited to RF signals; other suitable means, e.g., infrared and other light wavelengths, ultrasonic links, and others can be utilized without departing from the overall scope and intent of the invention.

The system **100** of FIG. 6 can be modified as shown at 100′ in FIG. 6A, wherein the wireless master device **170m** and a first wireless servant device **170s1** establish therebetween a first wireless backplane link **118W1** via RF or other wireless communication means. The wireless master device **170m** and a second wireless servant device **170s2** establish therebetween a second RF wireless

backplane link **118W2**. The wireless master device **170m** and a third wireless servant device **170s3** establish therebetween a third RF wireless backplane link **118W3**. In order to establish more secure or fault-proof communication, backup communication paths are then established. For example, the wireless master device **170m** and the third wireless servant device **170s3** establish therebetween a fourth RF wireless backplane link **118R4**. Then the wireless servant device **170s3** and wireless servant device **170s1** establish therebetween a fifth RF wireless backplane link **118R5**. This combination **118R4+118R5** provides a backup path for link **118W1**. Other servant-to-servant wireless links such as **118R6** between servant modules **170s2** and **170s3** and wireless link **118R7** between servant modules **170s1,170s2** are likewise established to provide other communication paths that are alternatives to the direct communication path between wireless master device **170m** and a particular wireless servant device **170s1,170s2,170s3**. It is contemplated that, as a default condition, these redundant wireless links **118R4,118R5,118R6,118R7** be used in addition to the primary wireless links **118W1,118W2,118W3** to minimize the likelihood of a communication failure. Alternatively, the redundant links **118R4,118R5,118R6,118R7** are used only when a time-out or other failure is detected in connection with a primary wireless link **118W1,118W2,118W3**. It is also contemplated that the redundant wireless links **118R4,118R5,118R6,118R7** be of a different type (e.g., different RF protocol, different RF frequency, non-RF, etc.) as compared to the primary wireless links **118W1,118W2,118W3** to minimize the likelihood of simultaneous communication failures on both the primary and redundant wireless links. The foregoing provides an example embodiment for simple wireless backplane link redundancy. Multiple levels of redundancy can be provided by suitable application of these precepts.

As noted above in connection with FIG. 5, the relationship between the wireless devices **170m,170s1,170s2,170s3** can be a master-servant or peer-to-peer relationship. In such case, any wireless device **170m,170s1,170s2,170s3** can initiate communication with another on the respective primary wireless

backplane links **118W1,118W2,118W3**, and the terms "master" and "servant" as used herein are not intended to limit the development to a master-servant or "master-slave" relationship where only the primary wireless device **170m** can initiate communication on the wireless backplane links **118W1,118W2,118W3** with the secondary wireless devices **170s1,170s2,170s3**.

FIG. 7 illustrates a highly desired application of the system **100** in a simplified form. In the illustrated example, the system **100** comprises a network adapter **112** operatively connected to the industrial controller **IC** and scanner **S** by wired and/or wireless network connections **14,16** as described above. In general, the system **100** comprises a wireless master device **M** and multiple wireless servant islands **S1-S6**, wherein each wireless servant island comprises one or more I/O modules and/or field devices that must communicate with the industrial controller **IC** via network adapter **112** of the wireless master. As shown, the servant island **S1** comprises IP-20 modular I/O devices located in a cabinet enclosure **C1**; the servant island **S2** is simply a machine-mounted sensor field device; the servant island **S3** is a NEMA 4X (IP-65) modular I/O device; the servant island **S4** comprises a motor or other actuator field device; the servant island **S5** is defined by an IP-67 compliant block (non-modular) I/O device mounted to a machine or otherwise located in a harsh environment; and the servant island **S6** is intrinsically safe modular I/O located in an explosive environment. The wireless master device **M** includes a wireless master device **170m** and the islands include respective wireless servant wireless device **170s1-170s6** as described above.

It can be seen that the servant islands **S1-S6** are of mixed types and are located in mixed environments where hard-wired connections might be undesired or impracticable. As such, the system **100** provides for a modular input/output system with a wireless backplane extender wherein all of the islands can communicate with the master backplane **118M** of wireless master device **M** for communication with the industrial controller **IC** via respective wireless links **118W1-118W6** and, optionally via redundant wireless links as described above in relation to FIG. 6A.

In certain environments or applications, it can be critical that each servant island be guaranteed a communication link with the industrial controller at a time certain. Referring now to FIG. 8, it can be seen that the wireless links **118W1-118W6** respectively established between the wireless master device **M** and the servant islands **S1-S6** are initiated by the wireless master according to predetermined time slots T_1-T_6. Such a system thus requires that each servant island **S1-S6** be uniquely identified. In one preferred embodiment, the wireless master module **M** and the respective servant wireless modules **S1-S6** comprise a user selectable configuration device such as dip-switches, jumpers, and/or other configurable means (e.g., a programmable memory) for establishing a master device and for storing a unique identifier for each servant device. In addition to the time-sensitive or "real-time" data communicated in a time slot T_1-T_6, it is contemplated that the time slots T_1-T_6 will exceed the required bandwidth in terms of time and/or capacity and that this excess bandwidth be used to send data that are time-insensitive e.g., performance data, monitoring data, log data, etc. In an alternative embodiment, such as when a spread-spectrum wireless protocol is implemented, the wireless links **118W1-118W6** are established and allocated for use by the wireless master device **M** and the servant islands **S1-S6** according to a time and/or frequency slicing/hopping scheme where the wireless links **118W1-118W6** are dedicated to a particular frequency or are allocated a particular frequency in a select time slot to reduce the number of different frequencies and time slots used. By way of example, frequencies **F1,F2,F3** can be allocated during two time slots T_1 and T_2 to establish the six example wireless links **118W1-118W6** according to: **118W1=F1@T1, 118W2=F2@T1, 118W3=F3@T1, 118W4=F1@T2, 118W5=F2@T2** and **118W6=F3@T2.**

FIGS. 9A and 9B illustrates examples for the wireless master and servant device **M** and **S1-S6**, respectively. There, a portion of the housing is broken away to reveal that the wireless master device **M** comprises a user selectable configuration device such as a dip switch **D** for configuration by a user as the master and also comprises a visual display **V** that provides visual feedback to a user that the

module has been configured as the master, e.g., a symbol "M" or the like. Similarly, as shown in FIG. 9B where a portion of the housing is broken away, the wireless servant modules **S1-S6** comprises a user selectable configuration device such as a dip switch **D** for configuration as a particular one of the servant devices **S1-S6** and also comprises a visual display **V** that provides visual feedback to a user to this effect, e.g., a symbol "S2" or the like.

The wireless master **M** comprises an electrical connector **MC** that is connected to a master backplane **118M** or directly into the network adapter **112.** The master backplane can be integrated into the wireless master **M** or can be part of one or more other devices. The wireless servant modules **S1-S6** comprise an electrical connector **SC** for being connected to a servant backplane **118S** along with one or more I/O modules **120a-120f** and or other field devices such as sensors, motors and the like that must communicate with the industrial controller **IC** through the wireless master **M.**

As shown in FIGS. 9A and 9B, the master **M** and servant **S1-S6** devices can also comprise an interface **I,** which can be a cable interface (e.g., USB,RS-232) or a wireless (IR,RF) interface by which these devices can communicate with a user interface device **PC** (see FIG. 7) such as a desktop, laptop, hand-held computer or other device comprising a visual display. When the user interface device **PC** is connected to a wireless master or servant module **M,S1-S6,** the module communicates with the **PC** to provide data that describe the overall topology of the system **100** for viewing by a user on the visual display, including the physical location of the various modules **M,S1-S6,** the operating parameters of the device such as the type and quality of the various wireless links **118W1-118W6,** the type and number of I/O modules **120a-120f** or other devices connected to a particular wireless master or servant device **M,S1-S6** and/or in the entire system **100.** The user interface device **PC** can also be used to configure the wireless modules **M,S1-S6** as an alternative to jumpers or dip switches **D.** When the user interface device **PC** is connected to any one of the wireless master **M** or wireless servant devices **S1-S6,** directly or through network **16,** it can be used to select and configure, monitor

and/or otherwise interact with any other device **M,S1-S6** of the system. It is most preferred that a particular device **M,S1-S6** communicating with the user interface device **PC** provide a visual and/or audio output signal via indicators **176m,176s** or visual display **V** or audio speaker **K** to acknowledge its active communication with the user interface device **PC.**

Modifications and alterations will occur to those of ordinary skill in the art. It is intended that the claims be construed literally and/or according to the doctrine of equivalents so as to encompass all such modifications and alterations to the fullest extent available under the law.